Global eradication of poliomyelitis: benefit–cost analysis

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A benefit–cost analysis of the Poliomyelitis Eradication Initiative was undertaken to facilitate national and international decision-making with regard to financial support. The base case examined the net costs and benefits during the period 1986–2040; the model assumed differential costs for oral poliovirus vaccine (OPV) and vaccine delivery in industrialized and developing countries, and ignored all benefits aside from reductions in direct costs for treatment and rehabilitation. The model showed that the "break-even" point at which benefits exceeded costs was the year 2007, with a saving of US$ 13 600 million by the year 2040. Sensitivity analyses revealed only small differences in the break-even point and in the dollars saved, when compared with the base case, even with large variations in the target age group for vaccination, the proportion of case-patients seeking medical attention, and the cost of vaccine delivery. The technical feasibility of global eradication is supported by the availability of an easily administered, inexpensive vaccine (OPV), the epidemiological characteristics of poliomyelitis, and the successful experience in the Americas with elimination of wild poliovirus infection. This model demonstrates that the Poliomyelitis Eradication Initiative is economically justified.

Introduction

Developing countries are confronted with destabilizing health problems and with a serious shortage of resources. The prospects for per capita income growth in many countries have deteriorated, and the adoption of structural adjustment policies calls for a rigorous review of public investment programmes. The allocation of resources in the health sector in the past has not been efficient and equitable, owing to an emphasis on expensive urban and hospital-based curative care, and was not directed at the main causes of ill health in the majority of the population, especially in the less developed countries.

Only in the past decade has immunization, one of the least expensive and most cost-effective of all health interventions, which has been confirmed by cost analyses, been accorded a high priority (*1*). The prospect of removing the burden of a disease and its treatment for ever, and at the same time eliminating the continuing costs of vaccinations, is an attractive policy alternative. Prior to the development and introduction of poliomyelitis vaccine, up to 32 out of every 100 000 children born in the world had permanent lameness as a result of infection with poliovirus (*2–4*).

The early successes in the Americas, through the expanded programmes on immunization (EPI), led the Forty-first World Health Assembly in May 1988 to adopt a resolution (WHA41.28) to eradicate poliomyelitis from the world by the year 2000 (*5*). This goal was confirmed in 1990 at the World Summit for Children (*6*). Poliomyelitis eradication is an example of the EPI focus on the impact of immunization on a target disease. In addition, the progress towards such eradication is seen as providing a measure of the progress towards achieving the WHO goal of Health for All by the year 2000, i.e., reaching and maintaining >90% coverage with current EPI antigens for all children (*7*, *8*). Under WHO's global leadership of EPI, an estimated 80% of the world's children were fully immunized in 1993 against poliomyelitis; even so, the disease still causes paralysis in over 100 000 individuals each year and kills perhaps more than 10 000 (*9*).

The decision to undertake eradication has economic implications for the poorest countries and donors who are concerned about the potential to divert resources from other activities with a potentially greater impact or to interfere with the development of primary health care (*10–13*). A benefit-cost analysis of global poliomyelitis eradication was therefore recommended so that decisions about national and international financial support for this effort could be made.

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Reprint No. **5670**

Methods

The model

The global poliomyelitis eradication programme has been modelled as a unit effort from the beginning of the first eradication efforts, with projections beyond eradication; benefits have been calculated up to the year 2040. The number of children to be immunized with oral poliomyelitis vaccine (OPV) annually, the disease incidence and morbidity, and the vaccine's efficacy permit an estimation of the number of cases prevented by vaccination and the cost of achieving these reductions. Reductions in the morbidity and mortality, and the consequent drop in demand for treatment and rehabilitation constitute the principal benefits of OPV vaccination in the base case (see below). In addition, in order to approach a more complete estimate of net present value, additional direct benefits of eradication, i.e., the savings in vaccine and its delivery, have been added to the treatment and rehabilitation costs and compared with the cost of the programme to determine whether the programme is economically justifiable (*14–18*).[a–c]

The analysis has attempted to maximize the costs and minimize the benefits in order to construct the least favourable balance in the benefit-cost relationship of poliomyelitis eradication. Because it is difficult and often controversial to place dollar values on many of the elements on the benefit side of the benefit-cost equation, only the savings in treatment and rehabilitation following the reduced incidence of disease have been used as the benefits in this analysis. If eradication can be seen to have a favourable benefit-cost ratio while ignoring all other tangible reductions in the costs to the community and the family, the long-term handicaps, the value of life and income calculations as well as intangible and external benefits, it would be expected to be even more cost-beneficial when these other benefits are taken into account, no matter how or at what level they are valued. In addition, this approach enables comparison with the analysis that was carried out for the Americas (*19*).

For each of the years of the model programme, estimates were made of the number of paralytic poliomyelitis cases that would be prevented, the costs of treatment and rehabilitation of that number of poliomyelitis cases, the cost of the eradication effort (the vaccine, the cold chain, administration of the programme, the deployment of delivery teams, social mobilization and the immunization strategy chosen), and the net benefit (i.e., the reduced treatment and rehabilitation costs). The analysis compares the annual total costs with the total benefits throughout the entire period from pre-eradication till after eradication (*20, 21*).[d]

The analysis presented is a model designed to simulate as closely as possible the global eradication programme now being undertaken. While the model simulates what is taking place, some inputs, costs and programme projections can only be estimated and may differ from country to country within regions as well as between regions. For example, what proportion of a childhood population will be reached during a national vaccination day, "mop-up",[e] or outbreak response; and will there be just 5 years of national vaccine days or more than that, 2 years of mop-up, and the undertaking of significant outbreak response activities? Estimates of costs and benefits and projections were selected from country experiences.

Sensitivity analyses were performed where differing programme strategies, e.g., age of the target population for national vaccination days, discount rate and the cost of vaccine, or where costs vary widely in published data between country experiences, such as the cost to immunize a child or the amount of vaccine wastage. Only one assumption is varied at a time in the base case to test the effect of each parameter in question. Since the estimates of costs are only available from some countries, data reviews and surveys for the less developed countries[f–i] and for industrialized countries[j] were used in addition to individual published

[a] **EPI.** Poliomyelitis surveys by regions. *EPI Information System.* Section 3, Table 3.4, July 1988 (unpublished).

[b] **World Health Organization.** *Global poliomyelitis eradication by the year 2000: plan of action.* Revised 1992. Unpublished document WHO/EPI/Polio/92.2, 1992.

[c] **World Health Organization.** *Progress towards the global eradication of poliomyelitis: status report.* March 1994. Unpublished document WHO/GPV/Polio/94.1, 1994.

[d] **Garlow DC.** *Mass vaccination to combat polio: a cost-benefit analysis for Brazil.* Instituto de Pesquisas e Estudos Econimics, Universidade Federal de Rio Grande Do Sul, 1993 (in English, unpublished).

[e] Mop-up efforts are intensive house-to-house vaccination campaigns designed to reach and immunize children who are at special risk of infection.

[f] **World Health Organization.** *Expanded Programme on Immunization: EPI costing guidelines.* Unpublished document WHO/EPI/79/5, 1979.

[g] **Brenzel L.** *The cost of EPI: lessons learned from cost and cost-effectiveness studies of immunization programs.* REACH Project Paper, 1990 (unpublished document).

[h] **Patriarca P.** *Cost of delivering OPV in the developing world — Egypt, Vietnam.* Personal communication, 1993.

[i] **John TJ.** *Cost of full immunization with IPV and OPV vaccine and treatment and rehabilitation for poliomyelitis, North Arcot District in India* (personal communication, 1991).

[j] **Grabowski M.** *Cost of IPV and OPV vaccine and delivery of vaccine in the industrialized countries of the European Region* (personal communication, 1992).

reports and personal communications to establish cost parameters.

Two additional models were constructed, the first using 1988, the year of the World Health Assembly resolution on eradication of poliomyelitis, as the base year and measuring the marginal additional costs and benefit–cost of moving from control of the disease to eradication. In the second, benefits included savings in the cost of vaccine and delivery as well as treatment and rehabilitation in order to reflect more closely the true benefits of poliomyelitis eradication.

The base case and sensitivity analyses

(1) The base case includes the identification, valuation and summation of the cost and benefits in each year of the project's life. Costs (C) and benefits (B) were summed over the years, projected and discounted to calculate the Net Present Value using the formula given below. The present value of this stream of net benefits is the sum of these individual terms over the years of the model programme. In the model, net benefits remain positive, but because of discounting the benefits are smaller in future years.

$$\text{Net Present Value} = \sum_{i=0}^{n} \frac{B_i - C_i}{(1+r)}$$

(2) Eradication of poliomyelitis is taken as that point where the transmission of the causative organism has ceased in an irreversible manner, vaccine is no longer in use and, as a result, cases and infection have disappeared from all countries of the world.[k]

(3) The estimates of global population, the global birth cohort and the population living in industrialized and developing countries in each region are derived from the 1992 mid-year United Nations population estimates (*22*). No attempt has been made to incorporate the growth rate into the cohort to be vaccinated.

(4) The population to be vaccinated during the routine vaccination programme is estimated as the 1992 global birth cohort of surviving infants (133 831 500, of which 115 272 400 are in the developing world and 18 559 100 are in the industrialized world and Eastern Europe) who receive four doses of OPV during routine immunization (at birth, 6, 10 and 14 weeks) during the first year of life.[l] It is projected that 90% of the target population is reached. In addition, children aged 13–59 months (1–5 years) who have been identified with incomplete vaccination during routine facility-based vaccination sessions during their first year of life are assumed to be vaccinated at these routine contacts. It is estimated that 1/5 of unvaccinated children aged 13 to 59 months are identified and vaccinated each year.

(5) Immunization coverage estimates are those estimated and reported by the EPI as of October 1993. Coverage estimates are for three doses of oral poliomyelitis vaccine (OPV 3), since no systematic coverage estimate for the birth dose is available. Costs are projected for four doses to all children, i.e., as if all infants had received a birth dose, to maximize the costs of the model.

(6) National vaccination days are projected twice a year for 5 years in addition to the routine vaccination programme for all children aged ≤59 months. These are projected as two doses one month apart. It is projected that 90% of the target population is reached during each national vaccination day. Sensitivity analyses are done for target populations aged ≤36 months and ≤48 months (Table 1).

(7) In addition, after 5 years of national vaccination days are completed, in response to the continued occurrence of cases, 10% of children aged ≤59 months are projected to be vaccinated in annual "mop-up" campaigns. It is projected that 90% of the target population is reached during each mop-up campaign. These are projected as two doses one month apart for two years. Sensitivity analyses are done for target populations aged ≤36 months and ≤48 months, with 1% and 0.1% of all children targeted to be vaccinated.

(8) Outbreak response is projected surrounding cases in which 1% of all children aged ≤59 months are immunized with two doses one month apart. It is projected that 90% of the target population is reached during outbreak response. Sensitivity analyses are done with 0.1% of children aged ≤59 months vaccinated.

(9) Vaccination costs are expressed in 1993 US dollars, and are based on the planned regional programmes of eradication (Table 2). All costs are modelled beginning in 1986. The programme for the Americas is assumed to have begun in 1986 with national vaccination days and outbreak control car-

[k] **World Health Organization.** *Certification of the global eradication of poliomyelitis. Meeting of a working group.* Unpublished document EPI (Poliol/93.1), 1993.

[l] The choice of vaccination schedule and vaccine (OPV or eIPV) differs within and between the countries of the developing and industrialized world. The WHO-recommended schedule of four doses of OPV in the first year of life is used in developing countries. In the industrialized world at least five countries us eIPV solely as the primary series and at least three countries use OPV and eIPV.

Table 1: **"Base case" costs and benefits and sensitivity analysis for poliomyelitis eradication programme model**

I. Costs	
1. *Routine vaccination*	
a. Population ≤12 months old	133 830 000 plus 20% of 1–5-year age group (107 064 000)
— Industrialized countries	18 560 000
— Developing countries	115 207 000
b. Industrialized countries	
Vaccine cost — OPV	US$ 4.16/dose (base case)
Delivery cost — OPV	US$ 5.09/dose (base case)
c. Developing countries	
Vaccine cost — OPV	US$ 0.08/dose (base case)
(Sensitivity analysis:	US$ 0.12/dose)
Delivery cost — OPV	US$ 1.51/dose (base case)
(Sensitivity analysis:	US$ 3.00/dose)
d. Wastage	
OPV	33%
(Sensitivity analysis:	50%)
2. *Accelerated vaccination activities (national vaccination days (NVD), mop-up, outbreak control)*	
a. Population ≤59 months age	669 150 000
— Industrialized countries	92 800 000
— Developing countries	576 350 000
(Sensitivity analysis:	for mop-up 1% and 0.1%; for outbreak control 0.1% of the target population.)
b. Industrialized countries	
Vaccine cost — OPV	US$ 4.16/dose
Delivery cost — OPV	US$ 1.48/dose
c. Developing countries	
Vaccine cost — OPV	US$ 0.08/dose
Delivery cost — OPV	US$ 0.10/dose
(Sensitivity analysis:	US$ 0.79/dose
3. *Target population for accelerated activities* ≤59 months old (base case) (Sensitivity analysis ≤48 and ≤36 months old)	
4. *Discount rate* (Sensitivity analysis at 0%, 3%, 10%)	6%
II. Benefits	
Case of paralytic poliomyelitis — pre-EPI 5/100 000 (Sensitivity analysis: 2/100 000 and 19/100 000)	
Proportion of paralytic cases receiving treatment and rehabilitation	
Industrialized countries	100%
Developing countries	33%
(Sensitivity analysis:	0%)
Cost of treatment and rehabilitation	
Industrialized countries	US$ 25 000/case
Developing countries	US$ 250/case

ried out for 5 years until 1990, with mop-up efforts that continued for two additional years. Routine immunization is planned to continue till the year 2005 when eradication is projected to be declared globally.

For the Western Pacific Region (WPR) the programme is assumed to have begun in 1991 with "subnational vaccination days" (20% of the children less than 5 years of age) having been carried out for two years prior to the first national vaccination days in 1993. It is projected that 90% of the target population was reached during each subnational vaccination day. Children were vaccinated with two doses one month apart.

In the European Region (EUR) only one-third of the population are in countries expecting to conduct national vaccination days, i.e., the former Soviet Union, the former Yugoslavia, Turkey, Romania, Bulgaria and Albania. This effort is projected to have begun in 1992, and 90% of the target population was reached with two doses one month apart.

In the Eastern Mediterranean Region (EMR) two years of subregional vaccination days began in 1992 to be followed by national vaccination days for five years. Subregional vaccination days are defined as targeting 10% of the children aged ≤59 months for vaccination with two doses one month apart. It is projected that 90% of the target population was reached.

National vaccination days began in the South-East Asia Region in 1994 although individual countries e.g. India, started subnational vaccination days in 1992. The African (AFR) Region began national vaccination days in 1995. It is projected that there will be 90% coverage with two doses one month apart.

(10) Globally, each country will be monitored for three years by a Global Eradication Certification Committee after the last case of poliomyelitis has been reported, and after vaccinations have been stopped and poliomyelitis is declared as eradicated in the year 2005. Routine immunization is projected to continue in all regions until they are polio-free.

(11) Although an incidence as high as 32 per 100 000 has been reported, the global incidence of paralytic poliomyelitis at the outset of the eradication effort is estimated conservatively at 669 158 or 5 per 100 000 surviving newborns.

(12) It is assumed for the purposes of this calculation that, in industrialized countries, 95% of those vaccinated with OPV were immunized, i.e, developed detectable levels of neutralizing antibodies (*23*). In developing countries it is assumed that 80% of those vaccinated with OPV were immunized. From the limited data available, seroconversion rates with OPV during national vaccination days may be 10% higher than during routine immunization programmes, but this is not taken into account in these calculations.

Table 2: **Global poliomyelitis eradication model programme: projected activities, by WHO Region, 1986 to 2005**

Year	WHO Regions					
	Africa	Americas	Eastern Mediterranean	Europe	South-East Asia	Western Pacific
1986	Routine[a]	NVD[b] + Outbreak[c] + R	Routine	Routine	Routine	Routine
1987	Routine	NVD + Outbreak + R	Routine	Routine	Routine	Routine
1988	Routine	NVD + Outbreak + R	Routine	Routine	Routine	Routine
1989	Routine	NVD + Outbreak + R	Routine	Routine	Routine	Routine
1990	Routine	NVD + Outbreak + R	Routine	Routine	Routine	Routine
1991	Routine	Mop-up[d] + Routine	Routine	Routine	Routine	Subnational[e] + Routine
1992	Routine	Mop-up + Routine	Subregional[e]	NVD/3[f] + Outbreak + R	Routine	Subnational + Routine
1993	Routine	Routine	Subregional	NVD/3 + Outbreak + R	Routine	NVD + Outbreak + R
1994	Routine	Routine	NVD + Outbreak + R	NVD/3 + Outbreak + R	NVD + Outbreak + R	NVD + Outbreak + R
1995	NVD + Outbreak + R	Routine	NVD + Outbreak + R	NVD/3 + Outbreak + R	NVD + Outbreak + R	NVD + Outbreak + R
1996	NVD + Outbreak + R	Routine	NVD + Outbreak + R	NVD/3 + Outbreak + R	NVD + Outbreak + R	NVD + Outbreak + R
1997	NVD + Outbreak + R	Routine	NVD + Outbreak + R	Mop-up + Routine	NVD + Outbreak + R	NVD + Outbreak + R
1998	NVD + Outbreak + R	Routine	NVD + Outbreak + R	Mop-up + Routine	NVD + Outbreak + R	Mop-up + Routine
1999	NVD + Outbreak + R	Routine	Mop-up + Routine	Routine	Mop-up + Routine	Mop-up + Routine
2000	Mop-up + Routine	Routine	Mop-up + Routine	Routine	Mop-up + Routine	Routine
2001	Mop-up + Routine	Routine	Routine	Routine	Routine	Routine
2002	Observation	Observation	Observation	Observation	Observation	Observation
2003	Observation	Observation	Observation	Observation	Observation	Observation
2004	Observation	Observation	Observation	Observation	Observation	Observation
2005	**Eradication**	**Eradication**	**Eradication**	**Eradication**	**Eradication**	**Eradication**

[a] Routine (R) vaccination: 4 doses of OPV administered to 90% of all children ⩽12 months old: at birth and at 6, 10 and 14 weeks of age.
[b] National vaccination days (NVD): 2 doses of OPV one month apart administered to 90% of all children ⩽59 months old.
[c] Outbreak response: 2 doses of OPV one month apart delivered to 1% of all children ⩽59 months old.
[d] Mop-up: 2 doses of OPV one month apart delivered to 10% of all children aged ⩽59 months in persistently high-risk areas.
[e] Subnational and subregional vaccination days: 2 doses of OPV one month apart administered to 90% of all children aged ⩽59 months within a portion of a country or region. Subnational days target 20% of all children aged ⩽59 months; subregional days target 10% of all children aged ⩽59 months.
[f] NVD/3: the one-third portion of the children aged ⩽59 months in the European Region targeted for mass campaigns: 2 doses of OPV one month apart administered to 90% of the targeted children aged ⩽59 months.

(13) Analysis of secular trends in countries where substantial coverage has resulted in a significant reduction in disease demonstrates that with routine immunization programmes cases fall at an estimated 40% per year. With mass campaigns the reduction is estimated at 70% per year. The projected decline in cases with the continued application of vaccine is projected linearly for ease of presen-tation. At the end of the programme 669158 patient-cases are projected to have been prevented worldwide annually.

(14) Programme costs, treatment and rehabilitation costs, and vaccine costs are stratified by developing and industrialized countries and are presented in 1993 US dollars.

(15) The cost of acute care and subsequent rehabilitation is conservatively assumed to be US$ 25000 per case in industrialized countries and US$250 per case in developing countries. The base case assumes that only one-third of all cases in developing countries receive acute care and rehabilitation; 100% of cases are assumed to receive treatment and rehabilitation in industrialized countries. A sensitivity analysis is done assuming that only 10% of cases in developing countries receive acute care and rehabilitation; and that 0% of cases in developing countries and 75% in industrialized countries receive treatment and rehabilitation.

(16) The expenses of poliomyelitis vaccination, which are derived from studies sponsored by the expanded programme on immunization (EPI), are the result of summing capital costs (buildings, vehicles, refrigeration and the cold chain), operational costs (including staff salaries, supervision), and the cost of transport (including fuel and spare parts). Only the costs to the delivery system are used in this model. In addition to the costs of purchasing and delivering vaccine, additional resources are needed to effect eradication such as training, increased surveillance activities; improvements in the cold chain; improved laboratory support; data collection and processing, etc. Since the largest portion of the costs are due to vaccine and delivery, these additional costs are not included to streamline the model.

(17) For simplicity of the model it is assumed that all countries use only OPV, the WHO-recommended vaccine of choice. The cost of OPV for the programme in developing countries at 1993 UNICEF prices is US$0.08/dose at port of entry. Sensitivity analysis is done with OPV vaccine costs using US$0.12/dose (a 50% increase as an estimate of future inflation). In industrialized countries the average cost of OPV is US$4.16/dose.

(18) The cost of vaccinating a child in the developing world with OPV is estimated at US$1.51/dose. A sensitivity analysis is done at US$3.00. This is based on the EPI estimates that in the developing world the delivery system costs are estimated to be US$15.00 to fully immunize a child. Assuming OPV is given at 4 of the 5 visits required to fully immunize a child, the cost of fully vaccinating a child with OPV is estimated to be four-fifths of US$15.00/child. In order to fully test the benefit-cost relationship, the cost of vaccinating a child with all vaccines during each of these four visits is attributed to poliomyelitis, i.e., US$3.00/visit. For industrialized countries, estimates for the delivery of vaccine are estimated at US$5.09/dose.

(19) Based on EPI estimates, the cost of delivery during national vaccination days, mop-up and outbreak response activities in a developing country is US$0.10 per dose. A sensitivity analysis is done at US$0.79/dose. In industrialized countries the cost of a contact is US$1.48/dose. A sensitivity analysis is done at US$2.47/dose.

(20) The estimate of the benefits of poliomyelitis eradication takes no account of the reduced pain and suffering or deaths due to poliomyelitis, the greater productivity of individuals who would otherwise be paralysed and become unproductive, the improved quality of life, or the reduction of other vaccine-preventable disease that could be expected to result from a successful programme against poliomyelitis.

(21) As an additional model, eradication of the 267663 cases (2 per 100000, down from 5 per 100000) estimated to be occurring in 1988, the year of the World Health Assembly resolution on global eradication of poliomyelitis, is taken to represent the marginal additional costs to move from a routine vaccination programme directed at control of the disease to one directed towards eradication.

(22) To explore further the full net present value of eradication, a second additional model is projected, adding the costs of vaccine and delivery to those of treatment and rehabilitation as items of benefit.

(23) Costs and benefits are discounted at 6% annually. A sensitivity analysis is done at 0, 3 and 10%.

(24) Vaccine wastage is estimated at 33%. A sensitivity analysis is done at 50%.

(25) While vaccine-associated poliomyelitis can, in individual cases in industrialized countries, rarely be associated with substantial treatment and litigation

costs, and since the rate of vaccine-associated poliomyelitis is so low, vaccine-associated poliomyelitis has not been included in these calculations.

(26) The costs of treatment, rehabilitation and vaccination will end at eradication, and the net benefits accrued are estimated beyond the year 2007 for a total of 55 years.

Results

The base case

Using the assumptions and parameters described, the net costs and benefits of the global eradication of poliomyelitis were calculated for a period of 55 years from 1986 to 2040. As shown in Table 3, the costs exceed the net benefits in 2007, at a base case discount rate of 6%. By the year 2040, the saving will amount to US$ 13 640 million.

Fig. 1. **Global poliomyelitis eradication model: base case.**

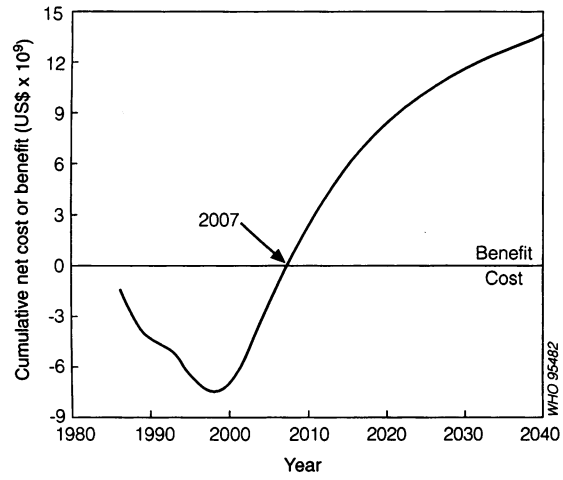


Table 3: **Net costs or benefits of global poliomyelitis eradication: base case and sensitivity analyses, for the year 2040**

	Costs or benefits in 2040 (US$ millions)	Year when benefits exceed costs
I *Base case*	13 640	2007
II *Sensitivity analyses*		
a. Target age of accelerated activities (base case ≤59 months):		
≤36 months	16 310	2005
≤48 months	14 970	2006
b. Proportion of target age reached by mop-up (base case 10%):		
1.0%	14 240	2007
0.1%	14 260	2007
c. Cost of routine vaccine (OPV) and delivery (base case is US$ 0.08):		
Developed countries US$ 3.00	13 690	2007
Developing country US$ 0.12	3 790	2024
d. Cost of accelerated activities/contact:		
Developing country US$ 0.79 (Base case US$ 0.10)	11 270	2010
Industrialized country US$ 2.47 (Base case US$ 1.48)	13 480	2008
e. Access to treatment and rehabilitation (base case 33% for developing and 100% industrialized):		
10%/100%	13 480	2007
0/100%	12 870	2008
0/75%	3 070	2023
f. Vaccine wastage (base case is 33%)		
50%	10 210	2011
g. Discount rate (base case is 6%)		
0%	86 130	2004
3%	34 500	2005
10%	1 850	2017
III *Additional models*		
a. Treatment and rehabilitation plus vaccine and delivery	27 360	2005
b. Acceleration from control to eradication (base case 5/100 000)	11 440	2010
2/100 000 to zero (treatment and rehabilitation plus vaccine and delivery)	3 380	2026

The net cumulative cost or benefits of the base case are shown in Fig. 1 in millions of US dollars. Each data point represents the net cumulative costs or benefits for the model programme to that date. The slope of the line falls as a result of net costs increasing as each of the Regions begins its accelerated vaccination efforts. In the year 2000 the benefits of the programme are seen as the number of averted cases increase, and the curve begins to turn upwards. For the base case, the year 2007 is the break-even point, the year in which the savings exceed the programme costs. From this point on, the benefits of the programme exceed the costs in every year, and the net benefits continue to increase. This increase continues after the planned end of the eradication effort since the benefits of eradication continue beyond the programme, i.e., through cases prevented and since treatment and rehabilitation are no longer needed.

As seen by the plateau of the curve, although the benefits of eradication continue in perpetuity (no cases with the attendant costs are occurring, and there is no longer any requirement to vaccinate), the dollar benefits decrease substantially as a result of discounting.

Sensitivity analysis

When alternative assumptions were tested, the eradication of poliomyelitis was still shown to be cost-beneficial. Different assumptions about the discount rate, the proportion of cases receiving treatment and rehabilitation, vaccine wastage, the age and proportion of the target population vaccinated during accelerated activities, and the cost of delivering immunization services may modify the results of the base case, but do not significantly alter them.

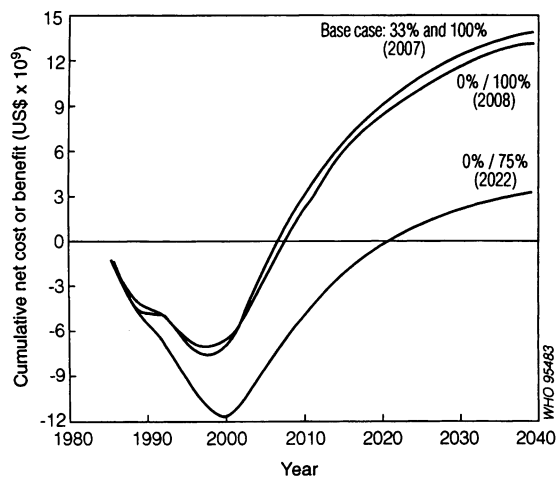
Target age of accelerated activities. Alternative target ages of accelerated immunization activities were evaluated. The base case assumes the target age is ≤59 months. The shortage of resources to purchase vaccine has the potential to force a lowering of the target age group for accelerated activities as was the case in China in 1992. For all target age groups eradication is cost-beneficial. Each year of lowering of age group in the target population to be vaccinated decreases the year of breaking even by one year: for the base case (≤59 months) the break even year is 2007; for ≤48 months it is 2006, and for ≤36 months it is 2005.

Cost of vaccine and delivery. The effect of an increase in OPV price from US$0.08 to US$0.12 has no significant impact on the year of breaking even or the overall slope of the curve (Table 2). Increasing the costs of delivering OPV by nearly eightfold in developing countries (US$0.79) had the effect of only delaying the year of breaking even by two years (Table 2).

Access to treatment and rehabilitation. The impact of varying the assumptions about access to treatment and the availability of rehabilitation in both developing and industrialized countries are assessed. Fig. 2 compares the base case (33%) with the overall impact of a reduction in treatment and rehabilitation rates to zero percent in developing world children. Little impact is seen on the shape, slope or break-even year. At zero percent of the developing world's children and 75% of the industrialized world's children reaching treatment and receiving rehabilitation, it is still cost-beneficial to eradicate poliomyelitis. The minimal treatment and rehabilitation rate at which eradication leads to savings is 0% access in developing countries and only 60% of children in industrialized countries receiving treatment and rehabilitation.

Vaccine wastage. The effect of vaccine wastage on net costs and net benefits is tested by increasing the vaccine wastage rate from the base case 33% to 50%.

Fig. 2. **Global poliomyelitis eradication: varying treatment rate assumptions in developing and industrialized countries.** Base case: in developing countries, 33% of acute poliomyelitis patients received care and rehabilitation; in developed countries, 100%. Sensitivity analyses: 0%/100% — no acute poliomyelitis patients receive care in developing countries, while 100% do so in industrialized countries; 0%/75% — no acute poliomyelitis patients receive care or rehabilitation in developing countries, while 75% do 80 in industrialized countries. The year in parentheses is the break-even year.



While this increase delays the time when net costs are exceeded by net benefits from the year 2007 to 2011, eradication remains cost-beneficial.

Proportion of the target population reached during accelerated activities. Reducing the population covered by mop-up and outbreak response from 1% to 0.1% had no significant effect on whether eradication or the year of breaking even is cost-beneficial, as compared to the base case (Table 2).

Discount rate. The effect of alternative discount rates is shown in Table 2. At a 3% discount rate, the break-even point is two years earlier as compared to the base case at 6% in the year 2007. Discount rates of 0% and 10% demonstrate a family of curves, all of which are cost-beneficial with break-even points between 2004 and 2017. The rate of 3% is more commonly used for social sector programmes such as poliomyelitis eradication. At 3% the net savings will be US$ 34 500 million by the year 2040.

Additional models

Addition of the cost of vaccine and delivery to the cost of treatment and rehabilitation as benefits. The annual global cost of routine vaccination with OPV under the base-case assumptions, which includes the cost of vaccine, delivery and wastage, is US$1774 million. If the costs of routine vaccination (vaccine and delivery costs) are added to the cost of treatment and rehabilitation as benefits accrued from eradication, the year of breaking even is 2005, two years earlier than for the base case (Table 2), and *precedes* the year of the declaration of eradication, which makes the eradication even more cost-beneficial.

Marginal additional costs of accelerating from control to eradication. After the World Health Assembly resolution (WHA41.28) had established the goal of global eradication of poliomyelitis, there was concern about the diversion of resources from primary health care development and other priority disease control activities towards eradication activities. Routine administration of OPV had reduced cases from an estimated 5/100000 to 2/100000 in 1988, the year of this resolution. This level would be expected to be maintained if there was no acceleration of activities towards eradication. Reducing cases from 2/100000 to zero represents the marginal additional cost of moving from control to eradication. The base case is compared with the acceleration of the programme beginning in 1988. Similar to the base case model, the benefits accrued were modelled in terms of treatment and rehabilitation alone, and treatment and rehabilitation plus vaccine and delivery costs. When the combined costs are tested, beginning with the level of 2 cases per 100000, an accelerated programme is cost-beneficial, and moves the break-even point to the year 2026. Poliomyelitis eradication, whether modelled from pre-eradication to eradication or as an acceleration from routine immunizations after the substantial initial impact, is cost-beneficial and saves US$ 3380 million. (Table 2).

Discussion

In spite of systematic underestimation of the benefits of a poliomyelitis eradication programme, there is evidence of positive and high returns from such an investment; the base case demonstrates that the net benefits exceed the net costs of the programme only two years after eradication is declared. By the year 2040, the savings will be US$ 13600 million. Poliomyelitis eradication, through sensitivity analysis and under the most stringently unfavourable test conditions, is economically beneficial, and the break-even point is always close to the date of eradication. This is true under various assumptions — increase in cost of vaccine and delivery, high vaccine wastage, limited access to treatment and rehabilitation, limited target age groups for accelerated activities, and high discount rates. The world would therefore not have to wait many years for eradication to pay off.

The eradication of poliomyelitis is a justifiable investment even without making any allowance for savings (benefits) other than those due to real reductions in expenditures to treat and rehabilitate some of the victims of the disease. Morbidity in the form of a post-poliomyelitis handicap affects a child's activity throughout life. This loss is associated with both real and intangible costs (missed work, unemployment, family loss of work time and income, reduction in anxiety, pain and the social stigma of handicaps). The cost of treating even a small fraction of those who need treatment and rehabilitation is large enough to pay for the total prevention of poliomyelitis. The addition of vaccine and delivery costs, which will cease after eradication, makes the tangible saving even larger — an additional annual savings of US$ 1700 million.

Experience with poliomyelitis epidemiology and with elimination of poliomyelitis in the Americas has demonstrated that eradication is technically feasible. Like smallpox, humans are the only reservoir of the virus, and there are no long-term carriers. An effective and inexpensive vaccine is readily available. While the ease of poliovirus transmission and the high infection-to-case ratio would suggest that the virus potentially is difficult to contain, little evi-

dence of this as an impediment has appeared in the Americas. Discussions of poliomyelitis eradication no longer include questions of feasibility, but rather focus on the extent to which eradication efforts could divert resources from interventions that would have a potentially greater health impact, or could interfere with the development of primary health care.

One technical controversy is related to EPI's continuous process of resolving programmatic issues. Discussions revolve around specific operational and implementation issues including the difficulties of seroconversion using OPV in tropical countries; the utility of outbreak response interventions; the feasibility of dependence on mass vaccination in all regions of the world; the appropriate target age for mass vaccination (≤59 months of age versus ≤36 or ≤48 months of age); and the requirement for mop-up operations in large areas. All these have been shown in this analysis not to affect the benefit-cost relationship, but only to lower or to extend the break-even year briefly.

Extension of the techniques used in the Americas to the other regions of the world where there are lower seroconversion rates with OPV, persisting cold chain problems, and less developed infrastructures continues to draw attention. The experiences in the Americas, however, suggest that these issues are not insurmountable, and we have now the opportunity to pursue the global eradication of a second disease of unacceptable morbidity and mortality after smallpox.

This analysis is based on a relatively rapid implementation of the overall eradication effort, with time limits for the implementation of eradication strategies between regions. If there is a major delay in either, then the threat of imported cases, continuing epidemics, and the need for more national vaccination days and mop-up activities will increase the cost of eradication substantially and the earlier benefits will be lost. A gradually increasing programme will clearly be more costly and will be a suboptimal strategy.

This model demonstrates that the eradication of poliomyelitis will make money available for other health programmes. Individuals and other parts of the health care system will benefit from poliomyelitis immunization in addition to the vaccinated children, the general reduction in the risk of infection giving all those at risk some benefits. Other external benefits stem from the institutional changes that accompany the increased accessibility, performance and credibility of effective health services. Instead of competing with the primary health care services, the eradication programe fosters the development of primary health care through a focused approach and the strengthening of managerial and other capacities of the primary health care system.

The acceleration from a routine programme to an eradication programme also demonstrated a favourable benefit-cost ratio with the expansion from the more limited inputs associated with control to full eradication. The public health strategy of disease eradication offers considerable advantages over disease control. The benefits of eradication are permanent and accrue long after the finite costs cease, while the costs of controlling the same disease must be maintained indefinitely.

The availability of an easily administered, inexpensive vaccine in OPV, the characteristics and epidemiology of poliomyelitis, and the experience in the Americas with successful elimination of wild poliomyelitis support the technical feasibility of eradication of poliomyelitis. These analyses demonstrate that poliomyelitis eradication is economically justified. Continuing delay in implementation will both increase the cost of achieving eradication and undermine past achievements. Sustained national and international support can be expected to lead to eradication and to generate significant savings for national governments.

Résumé

Eradication mondiale de la poliomyélite : analyse du rapport coût/avantages

Une analyse coût/avantages a été entreprise pour faciliter la prise de décisions financières à l'échelon national et international en vue de l'éradication mondiale de la poliomyélite. Seules les économies sur le coût du traitement et de la réadaptation résultant de la réduction de l'incidence de la maladie ont été prises en compte dans l'analyse du scénario de base. Si l'on peut montrer que l'éradication présente un rapport coût/avantages favorable sans tenir compte de toutes les autres économies tangibles ni des avantages intangibles ou indirects, on peut s'attendre à un rapport encore plus favorable si tous ces avantages sont pris en considération.

Le scénario de base envisage une population cible constituée de tous les enfants du monde âgés de 59 mois et moins (133 830 000); il suppose aussi que le coût du vaccin et de son administration n'est pas le même dans les pays industrialisés et dans les pays en développement, et que le taux de gaspillage du vaccin est de 33%. Les coûts du vaccin et de son administration ont été déterminés pour des campagnes de vaccination accélérées (journées nationales de vaccination, activités de ratissage et réponse aux épidémies); les avantages

et les coûts ont été actualisés au taux de 6%.

Des analyses de sensibilité ont été effectuées pour des populations cibles d'enfants d'âge différent (≤36 mois, ≤48 mois et ≤59 mois), pour différents taux d'actualisation (0%, 3%, 6% et 10%), pour différents taux de couverture du traitement et de la réadaptation dans les pays en développement (33%, 10% et 0%) et dans les pays industrialisés (100%, 75% et 60%), pour différents coûts d'administration du vaccin dans les pays en développement (US $0,10 et US $0,79/dose), et pour différents taux de gaspillage (33% et 50%).

Pour chacune des années du modèle, on a estimé le nombre de cas de poliomyélite paralytique évités, le coût du traitement et de la réadaptation, le coût des efforts d'éradication et les avantages nets. Les coût totaux annuels ont été comparés aux avantages totaux pour l'ensemble de la période, depuis la pré-éradication jusqu'à l'éradication finale. En outre, un autre modèle a été établi pour évaluer la différence entre le coût des activités de lutte contre la poliomyélite et le coût de l'éradication.

A partir des hypothèses et des paramètres du scénario de base, on a évalué le coût ou le bénéfice net de l'éradication mondiale de la poliomyélite pour une période de 55 ans allant de 1986 à 2040. La conclusion a été que le rapport coût/avantages était favorable. Selon le modèle, les coûts dépasseraient les avantages en 2007, mais en 2040, les économies s'élèveraient à US $13 600 millions. Dans toutes les hypothèses retenues pour l'analyse de sensibilité, les avantages dépasseraient les coûts du programme quelques années au maximum après l'éradication.

L'existence d'un vaccin peu coûteux et facile à administrer (VPO), les caractéristiques épidémiologiques de la maladie et le succès de l'élimination du virus sauvage dans les Amériques permettent de penser que l'éradication mondiale de la poliomyélite est techniquement réalisable. Les analyses décrites dans le présent article montrent qu'elle se justifie du point de vue économique.

References

1. **The World Bank.** *Investing in health. World development report 1993.* New York, Oxford University Press, 1993.
2. **Bernier RG.** Some observations on poliomyelitis lameness. *Rev. infect. dis.*, 1984, **6**: 371–375.
3. **Hajar MM et al.** Prevalence, incidence and epidemiological features of poliomyelitis in the Yemen Arab Republic. *Bull. Wld Hlth Org.*, 1983, **61**: 353–359.
4. **Heymann DL et al.** Estimation of incidence of poliomyelitis by three survey methods in different regions of the United Republic of Cameroon. *Bull. Wld Hlth Org.*, 1983, **61**: 501–507.
5. **World Health Organization.** Global eradication of poliomyelitis by the year 2000 (World Health Assembly resolution WHA41.28, 1988). In: *Handbook of resolutions and decisions of the World Health Assembly and the Executive Board. Vol. III, third edition (1985–92).* Geneva, 1993.
6. **United Nations.** *World Summit for Children. Plan of action.* New York, 1990.
7. **Melnick JL.** Vaccination against poliomyelitis: Present possibilities and future prospects. *Am. j. pub. hlth*, 1989, **79**: 1648–1652.
8. **Hinman AR et al.** The case for the global eradication of poliomyelitis. *Bull. Wld Hlth Org.*, 1987, **61**: 835–840.
9. **Hull HF et al.** Paralytic poliomyelitis: seasoned strategies, disappearing disease. *Lancet*, 1994, **343:** 1131–1137.
10. **Mushkin J.** Health as an investment. *Journal of political economy*, 1962, **9**: 129–157.
11. **Weisbrod BA.** *Economics of public health: measuring the economic impact of diseases.* Philadelphia, PA, W. Penn Press, 1961.
12. **Pan American Health Organization.** Director announces campaign to eradicate poliomyelitis for the Americas by 1990. *Bull. Pan Am. Hlth Org.*, 1985, **19**: 213–215.
13. *Poliomyelitis: Global eradication by the year 2000. Report of a WHO Expert Committee.* Geneva, World Health Organization, May 1989 (unpublished).
14. **Willems JS, Sanders CR.** Cost-effectiveness and cost-benefit analysis of vaccines. *J. infect. dis.*, 1981, **144**: 486–493.
15. **Cutting WAM.** Cost-benefit evaluation of vaccination programmes. *Lancet*, 1980, **2**: 634–635.
16. **Robertson SE et al.** Worldwide status of poliomyelitis in 1986, 1987, 1988, and plans for its global eradication by the year 2000. *World health statistics quarterly*, 1990, **43**: 80–90.
17. **Sabin AB.** Strategies for elimination of poliomyelitis in different parts of the world with the use of oral poliovirus vaccine. *Rev. infect. dis.*, 1984, **6**: s391–s396.
18. **Assaad F, Ljungars-Esteves K.** World overview of poliomyelitis: regional patterns and trends. *Rev. infect. dis.,* 1984, **6**: s302–s307.
19. **Musgrove P.** Polio eradication in the Americas is economically justified. *Bull. Pan Am. Hlth Org.*, 1988, **22**: 1–16.
20. **de Quadros CA, Henderson DA.** Disease eradication and control in the Americas. *Biologicals*, 1993, **21**: 335–343.
21. **Robertson RC et al.** Cost-effectiveness of immunizations: the Gambia revisited. *Health policy and planning*, 1992, **7**: 111–122.
22. **United Nations.** *Statistical yearbook 1990/91: thirty-eighth issue.* New York, Department of Economic and Social Information and Policy Analysis, Statistical Division, United Nations, 1993.
23. **Patriarca PA, Wright PF, John JT.** Factors affecting the immunogenicity of oral polio vaccine with developing countries. *Rev. infect. dis.*, 1991, **13**: 926–939.